Airway Ultrasound in Critically Ill Patients

A Narrative Review

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Airway assessment and management have a central role in critical care medicine. Airway ultrasound can help us evaluate the anatomy, facilitate interventions such as intubation in difficult airways and tracheostomy, prevent post-extubation complications, and diagnose dysphagia. In this review, we will summarize the current use of ultrasound in airway assessment and management in critically ill patients.

Key Words—airway management; ultrasound; dysphagia

Airway assessment and management have a central role in critical care medicine. Intubation and tracheostomy are two of the most common procedures performed in intensive care, but unlike elective procedures, urgent and emergent airway management entail an increased risk of major complications, such as hypoxia, hypotension, or cardiac arrest.[1-2] Moreover, laryngeal injuries due to intubation are common in critical care patients; the most frequent symptoms are dysphonia, hoarseness, and dysphagia. Laryngeal injuries require a proper diagnosis and treatment during admission and beyond discharge.[3]

Recently, Russotto et al. summarized the latest evidence on airway management of critically ill patients, but they did not include ultrasound.[4] Ultrasound allows physicians to identify many structures of the upper airway and knowing this sonoanatomy aids in performing endotracheal intubation or tracheostomy and diagnosing complications such as dysphagia or laryngeal injuries.

Airway ultrasound has slowly increased its applications in similar specialties such as anesthesia or emergency medicine, but its use in intensive care has lagged behind other ultrasound modalities. However, once integrated, it will become an invaluable tool in the intensivist's armamentarium. Ultrasound can help us evaluate the airway and provide rapid interventions in acute situations,[5-6] for instance, identifying the trachea in situations where localizing it is difficult due to a neck mass or any other swelling such a Ludwig's angina.[7] Additionally, it can help us predict difficult airways, together with clinical examination.[8]

The purpose of this review is to summarize the current use of ultrasound in airway assessment and management focusing on critically ill adult patients.

Methods

The authors performed a structured literature search using Embase, PubMed databases, and Google Scholar (Alphabet Inc.) with

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Abbreviations

BMI, body mass index; CL, Cormack–Lehane; FEES, flexible endoscopic evaluation of swallowing; HMD ratio, hyomental distance ratio; VFSS, videofluoroscopic swallow study

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the keywords "airway management," "ultrasound," "sonography," and "dysphagia." The literature search was performed at the end of October 2020 and was restricted to studies published in English from January 1, 2010, to October 1, 2020. The inclusion criteria were manuscripts published on medical disciplines of Intensive Care Medicine (Critical Care Medicine), Emergency Medicine, and Anesthesiology in adult settings. Pediatric-focused research was ruled out by excluding related terms from the title. Despite not being registered in PROSPERO, we searched their database to see if there were similar studies.

Two authors (CDT, LG) independently conducted the research looking for all published papers meeting the inclusion criteria. First, we classified the materials by reading the title and abstract and excluded the manuscripts that did not match the inclusion criteria. Then the remaining papers were analyzed based on reading the introduction and conclusion. We fully read all manuscripts that matched our inclusion criteria. The authors included case reports, retrospective and prospective studies, systematic reviews and meta-analyses, and other narrative reviews. Articles were included regardless of the risk of bias, since the aim of the review is descriptive. This is a narrative review; therefore, no ethical approval or consent was required.

Anatomy

Ultrasound allows to distinguish between the different anatomical structures, thanks to the ability of the tissue to reflect the ultrasound waves that is primarily determined by the density and the acoustic impedance of each tissue. Air reflects nearly 99% of ultrasound waves, complicating the evaluation of air-filled structures such as the lung or the airway. Ultrasound artifacts such as acoustic shadows or reverberations will help us identify the airway.[9]

Many structures can be identified during airway ultrasound (Figure 1):

- The bone is a hyperechogenic structure with a posterior hypoechogenic shadow. The hyoid bone would be seen as an inverted "U" in the transverse plane.
- The cartilages (thyroid, cricoid, and tracheal rings) are hypoechoic and homogeneous. Through the thyroid cartilage in the transverse plane, we can observe the vocal cords forming an isosceles triangle with a central tracheal shadow.
- The connective tissue and muscles are hypoechoic and heterogeneous. The air–tissue interface appears as an hyperechogenic line.
- The esophagus could be found adjacent to the first and second tracheal rings on the transverse plane or at the level of the suprasternal notch posterolateral to the trachea in the oblique transverse view. The physician can more easily identify the esophagus by asking the patient to swallow and checking the peristaltic movement of the esophagus.[7]

Technique

The ideal position to perform an ultrasound evaluation of the airway would be with the patient in a supine or semi-recumbent position with a little neck hyperextension. Most of the airway windows can be obtained using a linear or a convex transducer.[5,9] To optimize the image, the ideal depth should be between 2 and 5 cm and focus the ultrasound beam on the desired structure.

Procedures

Intubation

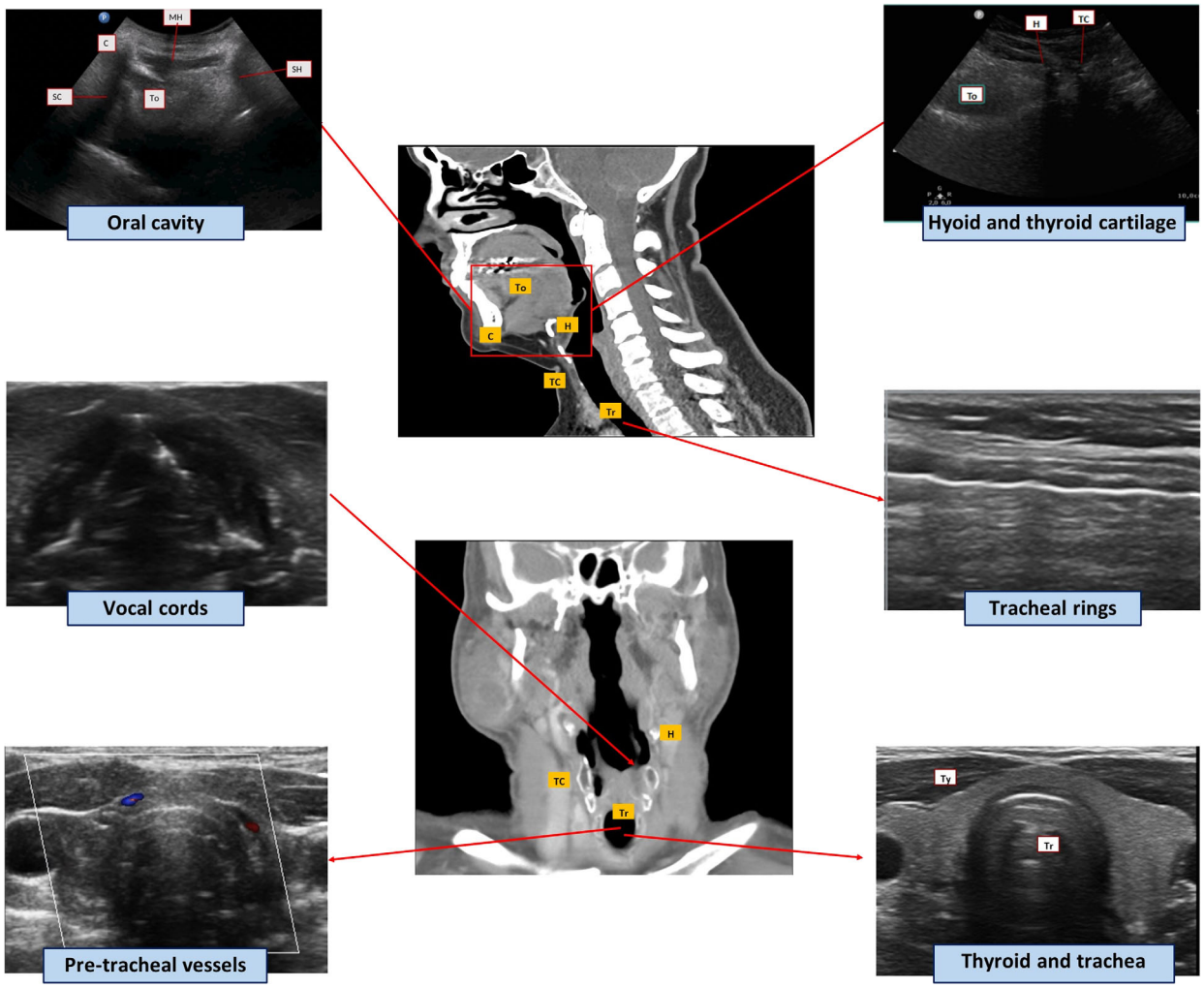
Tracheal intubation in the critically ill patient may occur on the intensive care unit itself or almost anywhere else in the hospital environment. Although around 30% of these tracheal intubations are emergent, most are urgent or semi-elective.[1] Urgent and emergent intubation entail an increased risk of major complications, such as hypoxia, hypotension, or cardiac arrest.[2]

Ultrasound can assist in different stages of endotracheal intubation.

Pre-intubation—The soft tissue of the neck can be assessed to dismiss the presence of masses or any other swellings, which could complicate the procedure or even make it necessary to choose an alternative airway device.[7] Ultrasound can also guide us in choosing the dimension of the tube using the size of the cricoid cartilage.[5-10]

During Intubation—Placing the probe in a transverse plane at the suprasternal notch, ultrasound can be used to dynamically observe the tube passage into the trachea or the esophagus. In an endotracheal

Figure 1. Sonographic images of airway anatomy correlated with computer tomography. C, chin; H, hyoid; MH, mylohyoid muscle; TC, thyroid cartilage; To, tongue; Tr, trachea; Ty, thyroid gland; SC, chin's posterior shadow; and SH, hyoid's posterior shadow.

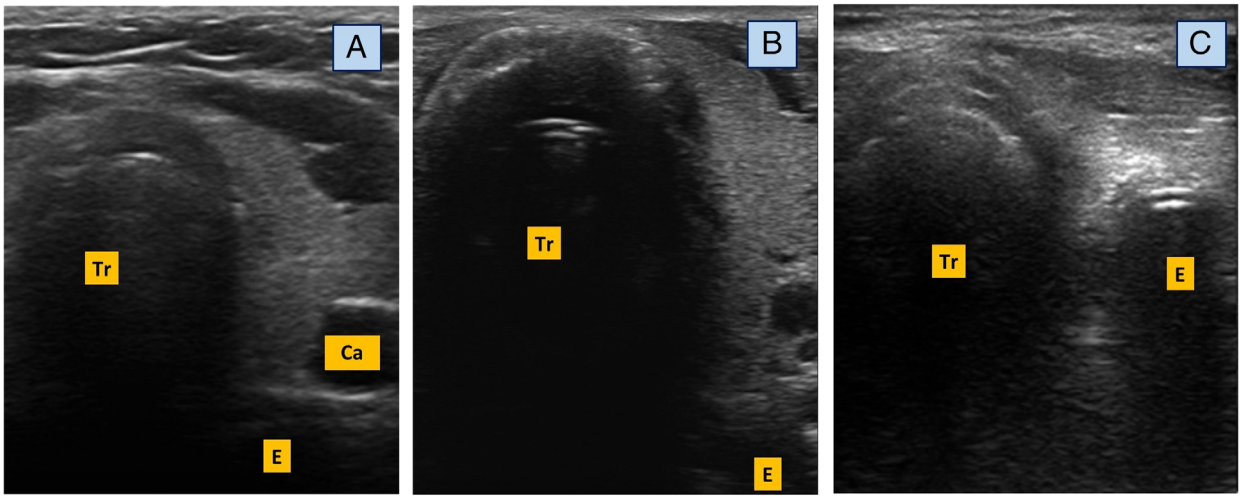


intubation, a semicircular image of the tube with two hyperechoic lines in the trachea should be seen (double tract or double-lumen sign).[5,11] In the case of esophageal intubation, the double-lumen sign is seen adjacent to trachea with an acoustic shadow and a sensitivity of 97 to 100%[9] (Figure 2 and online Supplemental Video 1).

Chou et al described the Tracheal Rapid Ultrasound Exam (T.R.U.E.) for confirming endotracheal tube placement during emergency intubation placing the transducer over the suprasternal notch.[12] The overall accuracy was 98.2% with a sensitivity of 98.9% and a specificity of 94.1%. Furthermore, this can be particularly helpful for physicians who are supervising a trainee performing intubation, allowing real-time confirmation of correct placement prior to bagging.

After Intubation—Capnography has been the gold standard for endotracheal tube placement confirmation.[13] Nevertheless, capnography is not so useful in some emergency situations, for instance, in cardiac arrest patients the absence of a detectable end-tidal carbon dioxide on waveform capnography does not rule out a successful intubation. Osman et al demonstrated the feasibility of upper-airway ultrasonography compared to waveform capnography for verifying

Figure 2. Trachea and esophagus with ultrasound probe in the axial plane above the suprasternal notch. **A,** Trachea and esophagus. **B,** Endotracheal intubation. Double tract sign in the trachea. **C,** Esophageal intubation. Double tract sign is seen adjacent to the trachea on the left side with an acoustic shadow. Tr, trachea; E, esophagus; and Ca, carotid artery



endotracheal tube location after intubation.[14] In fact, recent meta-analyses found that ultrasound has sensitivity greater than 93% and specificity greater than 95% for assessing the correct position of the tube.[15-17] Moreover, at the level of the suprasternal notch, Tessaro et al checked that inflating the endotracheal tube cuff with saline confirms the correct depth.[18] In addition, visualization of lung sliding or diaphragmatic movements can also indirectly confirm tracheal intubation.

Special Populations—In patients with increased neck soft tissue or obesity, a lower-frequency transducer may be used, which provides better penetration, to improve image quality.[9] In addition, in trauma patients, ultrasound can detect upper airway injuries secondary to blunt neck trauma which can lead to upper airway obstruction.[19,20]

The use of ultrasound for intubation requires a relatively simple and brief training,[4,9,11] so that it can be approachable for any intensivist. For instance, Chenkin et al used online training plus two real attempts, all physicians were able to distinguish between endotracheal and esophageal intubation.[11]

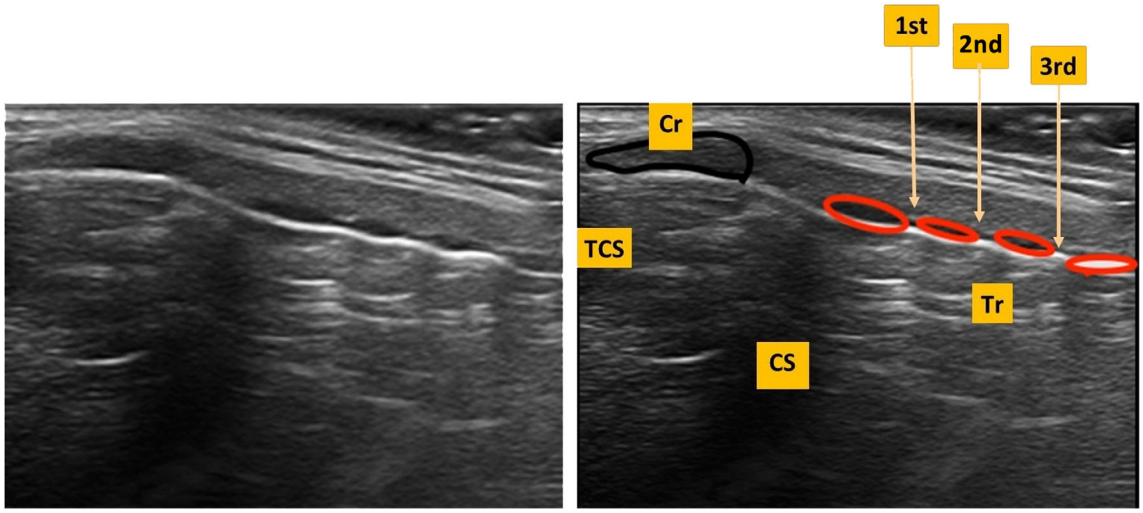
Tracheostomy

Ultrasound can also help with percutaneous dilatational tracheostomy or cricothyroidotomy.[21,22] It not only reduces complication rates by visualization of the tracheal rings and cricothyroid membrane to better locate the level of puncture and guide the procedure, but it also shows other structures that could be otherwise damaged, for instance, the posterior tracheal wall or some anterior neck structures including the thyroid vessels or the thyroid isthmus[4-6,23] (Figure 3).

Bleeding related to vascular anatomical variations is the most common complication when a percutaneous dilatational tracheostomy is performed. According to Simon et al, 1 out of every 600 patients has a percutaneous tracheostomy-related death and around 30% of these deaths occur during the procedure, secondary to a hemorrhage.[24] Even-Tov et al observed that a pre-procedural ultrasound could identify the patients with a major risk of bleeding because of a vascular anatomical variation or other types of variations in tracheal structure.[23] In this study, the management decision was changed from percutaneous to open surgical tracheostomy in 25% of the patients.

Before performing a percutaneous dilatational tracheostomy, an ultrasound review of the neck anatomy must be carried out to avoid injuring other structures. The point of tracheal puncture should be below the first tracheal ring but above the fifth tracheal ring without other structures in the path of the needle

Figure 3. Sonographic image of the cricoid cartilage and the tracheal rings in a longitudinal plane. Cr, cricoid cartilage; 1, first tracheal space; 2, second tracheal space; and 3, third tracheal space.



according to sonographic criteria. Firstly, in a transverse view, we should locate the tracheal midline. Then, rotate the probe 90° to obtain a longitudinal view with the cricoid cartilage and tracheal rings. This so-called in-plane approach allows following the needle as it is advanced. As the needle passes through the anterior wall, a change in resistance is felt and the lumen is entered, followed by the aspiration of air/fluid into the attached syringe. Afterward, the syringe is disconnected and a guide wire from a preassembled tracheostomy kit is inserted through the needle into the trachea as a guide for further tracheostomy. The position of the guidewire can also be verified in a transverse or oblique transverse view before dilatation of the trachea.[10,21,22]

Petiot et al[25] studied the learning curve for real-time ultrasound-guided percutaneous tracheostomy, finding that at least 50 procedures are necessary to perform this technique with an acceptable complication rate and procedure time.

Predicting Difficult Airway

Despite the existence of numerous clinical examinations for predicting difficult airways, such as mouth opening, thyromental distance, or Mallampati score (which determines the difficulty of intubation according to the tongue and pharyngeal structures); individually their predictive utility is limited.[8,10,26,27] Under urgent conditions, the feasibility of these tests is further diminished because of alterations in mental status or patient's respiratory distress, which prevent participation. A more reliable score to identify intubation in emergency settings is the seven-item MACOCHA score (Mallampati score III or IV, Obstructive Sleep Apnea syndrome, reduced mobility of the cervical spine, limited mouth opening, severe hypoxia, coma, and non-anesthesiologist) with a sensitivity of 73% and a specificity of 89%.[28]

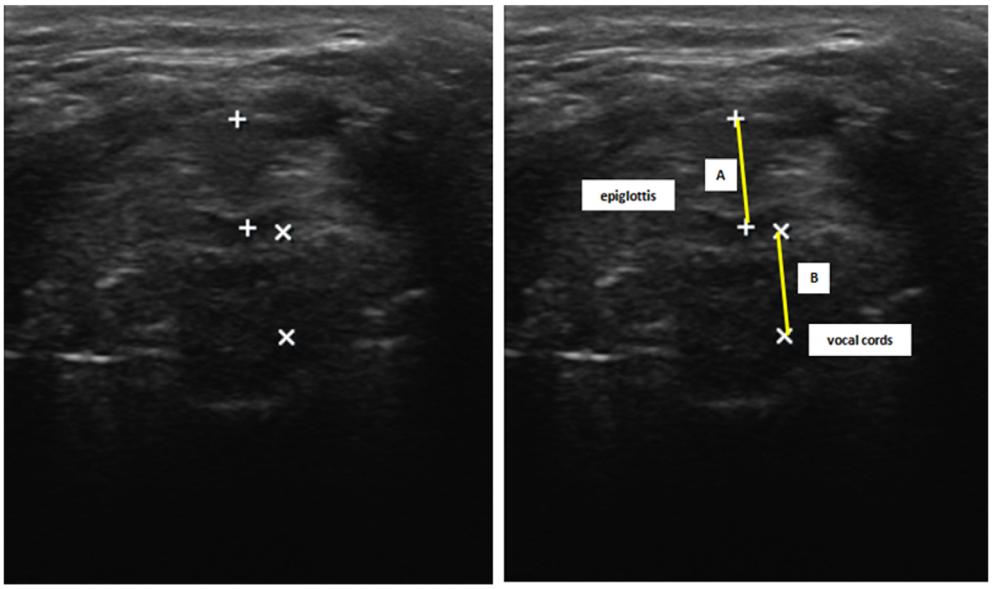
Ultrasound could play a role in predicting a difficult airway. Due to the poor reliability of traditional screening tools, any tool that can enhance airway assessment must be regarded as adjunct to the clinical examination. Not many studies compared traditional screening tools with ultrasound. Abdelhady et al compared Mallampati score and thyromental distance with ultrasound-measured distance from skin to epiglottis. They found a better correlation between ultrasound and Cormack–Lehane (CL) grading.[29]

Several ultrasound measurements have been described for predicting a difficult airway.[30-32] It is important to note that some of the studies involved patients undergoing elective surgery or healthy volunteers, limiting their applicability in unstable patients.

Soft Tissue Evaluation

The soft tissue thickness of the anterior neck measured at the level of the hyoid bone and epiglottis has

Figure 4. Ultrasound view of the oblique transverse plane. *A*/*B* ratio. (*A*) Depth of the pre-epiglottic space, (*B*) distance from the epiglottis to the midpoint of the distance between the vocal cords. Linear probe placed in the space between hyoid and thyroid cartilage and rotated in a caudal direction to obtain an oblique transverse view bisecting epiglottis and base of the vocal cords.



been shown to correlate with the CL grading. CL grading classifies views obtained by direct laryngoscopy into four grades based on the structures seen and tries to predict the likelihood of a difficult intubation, being grade 4 the most likely to have a difficult airway.[33] Various measurements of the soft tissue had been examined in many pilot studies, but no study has compared them so far, therefore, no single method is clearly better.

Rana et al performed an observational study with 120 patients that needed intubation for elective surgery.[34] They measured (*A*) the depth of the pre-epiglottic space and (*B*) the distance from the epiglottis to the midpoint of the distance between the vocal cords. They discovered that the *A*/*B* ratio could predict a difficult laryngoscopy, and it could be correlated with the CL grading. An *A*/*B* ratio of more than 1.77 had 82% sensitivity and 80% specificity in predicting difficult laryngoscopy (CL grade 3 or 4). Nonetheless, Gupta et al found that an *A*/*B* ratio between 2 and 3 correlated with CL grade 3.[35] Using the same ratio, Chan et al found that a lower cutoff point of this ratio ($A/B > 1$) should be used in the Chinese population for predicting a CL grade more than 3[36] (Figure 4).

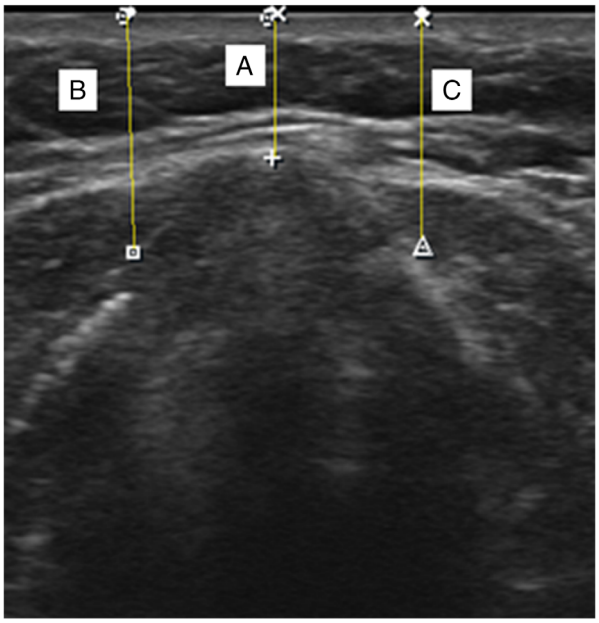
Other authors found that a difficult intubation could be predicted by anterior neck thickness above 2.8 cm at the level of the hyoid bone and thyrohyoid membrane.[31,37,38] Nazir et al found that an increase in anterior neck soft tissue distance at epiglottis level was strongly associated with a difficult intubation (cutoff value of 17.7 mm), and this was also correlated with CL grade.[39]

In obese patients, measuring pre-tracheal fat at the level of the vocal cords with a probe in the transverse plane can predict a difficult airway. Ezri et al measured the distance from the skin to the anterior aspect of the trachea at the midline and the anteroposterior distance at 15 mm to the left and right of the midline[40] (Figure 5). If the sum of these three measurements exceeds 28 mm in a patient with a neck circumference larger than 50 cm and a body mass index (BMI) > 35 kg/m^2, then it is predictive of a difficult laryngoscopy with a CL grade 3 or 4 in 70% of the cases.

Hyomental Distance Ratio

The hyomental distance (HMD) ratio is defined as the ratio of the distance between the hyoid bone and the tip of the chin in the neutral and head extended positions. Wojtczak et al observed that an HMD ratio shorter than 1 in obese patients predicts a

Figure 5. View of anterior cervical soft tissue at the level of the vocal cord. Distance from the skin to the anterior aspect of the trachea at the midline (A) and the anteroposterior distance at 15 mm to the left (B) and right (C) of the midline.



difficult airway.[41] Rana et al found that a ratio of less than 1.085 had a sensitivity of 75% and specificity of 85.3% in predicting a difficult laryngoscopy.[34] However, the sonographic measurement of the *A*/*B* ratio mentioned above is a better predictor of CL grading as compared to the HMD ratio. Petrisor et al found that dividing the HMD ratio in maximum hyperextension to that in the neutral position seems to be more accurate in predicting a difficult laryngoscopy in obese population in comparison with dividing the HMD ratio in the ramped position to that in the neutral position.[42]

Tongue

The tongue can be assessed with a submental view. Parameswari et al observed that a tongue thickness of more than 6.1 cm could predict a difficult laryngoscopy.[43] Wojtczak et al analyzed the tongue volume in obese patients and found no difference between the tongue volume and an easy or difficult intubation.[41]

Transverse Tracheal Air Shadow Diameter

The diameter of the transverse tracheal air shadow in the subglottic area of the neck can be measured as described by Lakhal et al.[44] Aydogmus et al performed a prospective trial in pregnant women and divided them into two groups according to a BMI lower or higher than 30 kg/m^2. No statistical differences were found between both groups concerning this measurement.[45]

There is a wide range of variability of results in the different studies to predict difficult airway by ultrasound and some studies are single center, had small samples size, or were performed in special populations. Unsurprisingly, there is no standardized method yet. Besides, some of these measurements are difficult to perform. Consequently, ultrasound utility decreases in urgent scenarios. Furthermore, no published guideline or paper indicates which patients should have their airway assessed by ultrasound since doing it to everyone is time consuming.

Detecting Complications

Extubation failure prolongs the duration of mechanical ventilation, increases the length of stay, and is associated with higher mortality.[46] Endotracheal tube causes a wide range of local complications. The most common laryngeal injuries are abnormal vocal cord mobility and laryngeal edema, which are associated with stridor and extubation failure.[3,47] Several studies have recognized ultrasonography as a tool that can be used to better identify them.[6,18,47]

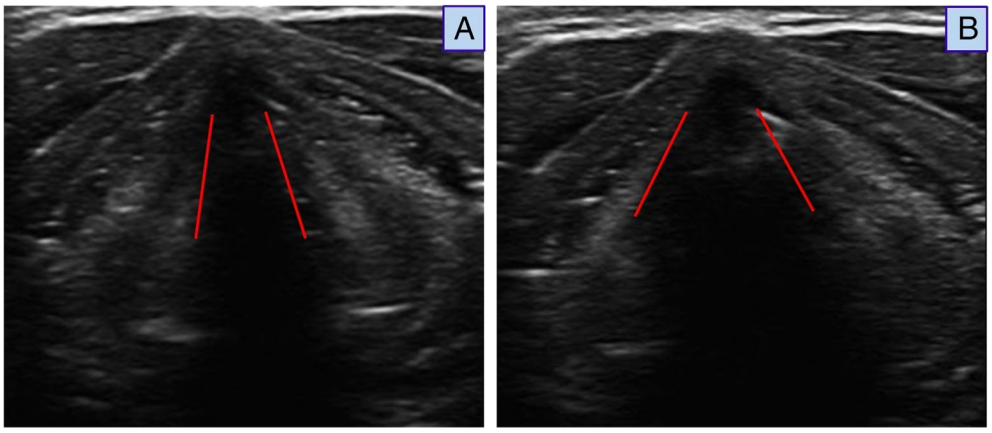
Laryngeal Edema

In order to predict stridor, several studies have used changes in the air-column width at the level of the vocal cords before and after endotracheal cuff deflation.[9,47] Despite being a promising measurement, studies had a small sample and results should be interpreted with caution (Figure 6).

Vocal Cord Dysfunctions

Vocal cord movement disorders are usually diagnosed by nasopharyngoscopy. However, it is an invasive technique that cannot be done on patients with severe coagulopathy or craniofacial trauma and, on some occasions such as glottic edema, fails to assess the vocal cords. Ultrasound can assess the vocal cords even in these situations and noninvasively[5,13] (online Supplemental Video 2). Ruan et al observed that ultrasound was a rapid primary screening method for vocal cord injuries, such as vocal cord paralysis or arytenoid cartilage dislocation using a linear probe at

Figure 6. Evaluation of the laryngeal air column width at vocal cords level. **A,** Square-shaped air column with acoustic shadow during balloon–cuff inflation: arytenoid cartilage and true vocal cords should be seen. **B,** Trapezoid-shaped air column after balloon–cuff deflation in a patient who did not develop post-extubation stridor: arytenoid cartilage and true vocal cords are not properly seen because of the acoustic shadow.



frontal transverse or lateral longitudinal plane.[48] Thus, not only can ultrasound assess the damage in vocal cords after extubation, but it can also be used in any patient with dysphonia[49] or even in patients with speech–language pathology as a part of their diagnostic evaluation.[50]

Dysphagia

Swallowing problems are commonly encountered in critically ill patients. A large prospective study showed that 18.3% of nonselected emergency admissions suffered post-extubation dysphagia,[51] and a recent meta-analysis found an overall weighted dysphagia incidence of 41%.[52] Many articles have been published in the past 2 years focusing on this topic. With a growing interest in screening these patients, maybe it is time to include ultrasound in this evaluation.[53,54] On the other hand, the act of deglutition is a complex process that involves three stages: oral, pharyngeal, and esophageal. Videofluoroscopic swallow study (VFSS) and flexible endoscopic evaluation of swallowing (FEES) tests are reference standards for dysphagia evaluation. VFSS provides views of the three stages but requires ionizing radiation. FEES can be done at bedside and provides a direct view to evaluate the nasopharynx, pharynx, and larynx, but it is an invasive technique and requires that the patient has no major bleeding risk or facial trauma. Ultrasound allows visualization of the motion of anatomical structures involved in the first two parts, such as the tongue, the hyoid bone, or the thyroid cartilage and detection of pharyngeal residues and aspirations[55] (online Supplemental Video 3). Compared to the VFSS and FEES, ultrasound is noninvasive, without short- and long-term complications and can be repeated as needed during follow-up.

Many measurements have been described, mostly in small studies. Huang et al assessed the reliability of using hyoid–larynx approximation, the distance obtained by subtracting the distance between the hyoid bone and thyroid cartilage during swallowing from the resting distance, and they found that patients with dysphagia had less approximation.[56] Yabunaka et al[57] evaluated hyoid bone movements in healthy volunteers while Macrae et al[58] found that the hyoid displacement measured with ultrasound had a good intra- and inter-rater agreement of more than 0.85. Tommii et al[59] described the Tongue and Oral Function test with Ultrasound using the M-mode and measuring the displacement of the tongue during swallowing. In 2018, Manabe et al[60] used tissue Doppler imaging to assess the cervical esophagus, not only the movement but also the velocity during swallowing, and they found that the method was reliable, reproducible, and well tolerated. Aspiration is detected as hyperechoic, long, narrow objects that pass through the vocal cords beneath the anterior wall of the trachea in B-mode video ultrasonography.

The sensitivity of aspiration detection was 0.64, and the specificity was 0.84.[61] Pharyngeal post-swallow residues can be detected above the vocal cords, in the pyriform sinus or the epiglottic vallecula as described by Miura et al.[62,63] The same group conducted a randomized controlled trial to investigate the effectiveness of ultrasound-guided swallowing care that showed a reduction in the residues and the frequency of aspirations in the intervention group.[64]

More Applications

Airway sonography is also useful to other applications such as detecting subglottic stenosis,[6] which is asymptomatic until the stenosis exceeds 50% of the tracheal section,[65] detecting esophageal impaction,[66] or in the assessment of epiglottitis.[67,68]

Conclusions

Ultrasound use is increasing exponentially in the management of critically ill patients. Other ultrasound modalities are completely integrated into critical care medicine, but that is not the case for airway sonography. Airway ultrasound could be a useful tool for intensivists. Assisting in intubation and tracheostomy and helping in the diagnosis of laryngeal injuries and dysphagia are some of the uses that could help improve patient's care and safety in critically ill patients.

Airway ultrasound shows signs of being an effective tool in critical care. However, further research is needed not only to validate some of the measurements and techniques but also to validate the education learning curve.

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